Overview: Languages, Grammars, and BNF

In this assessment, you will write a class GrammarSolver that will be able to generate random sentences (or other output) from a set of specially-formatted rules. These rules are called a grammar and are used to define a language. Our grammars will be written in Backus-Naur Form (BNF).

Formal Languages

A formal language is a set of words and symbols along with a set of rules defining how those symbols may be used together. These rules dictate what are considered valid constructions in the defined language. For example, in English, “A boy threw the ball.” is a valid sentence, but “A threw boy ball the” is not, despite consisting of the same words, because the words are put together in an invalid way.

Grammars

A grammar is a way of describing the syntax and symbols of a formal language. Grammars have two types of “symbols” (e.g., words, phrases, sentences): terminals and non-terminals. A terminal is a fundamental word or symbol in the language. For example, in English, any single word would be considered a terminal. A non-terminal is a symbol that is used to define specific groups of symbols that may be used in the language. In a grammar for English, we might have non-terminals such as “adjective,” “noun phrase,” and “sentence” to name a few.

For example, consider the following simple language:

- **Terminals**: the, a, cat, dog, runs, walks
- **Non-terminals**:
  - **sentence**: “article and object and verb”
  - **article**: “the or a”.
  - **object**: “cat or dog”.
  - **verb**: “runs or walks”.

This language allows the following sentences:

- “the cat runs”
- “the cat walks”
- “a cat runs”
- “a cat walks”
- “the dog runs”
- “the dog walks”
- “a dog runs”
- “a dog walks”
Backus-Naur Form (BNF)

*Backus-Naur Form (BNF)* is a specific format for specifying grammars. Each line of BNF looks like the following:

```
nonterminal ::= rule | rule | ... | rule
```

Each “rule” is some sequence of terminals or non-terminals separated by whitespace. The ‘|’ character separates different possible rules for the same non-terminal. For example, the grammar specified above written in BNF would look like:

```
sentence ::= article object verb
article ::= the | a
object ::= cat | dog
verb ::= runs | walks
```

Notice that the non-terminal `sentence` has a single option consisting of multiple non-terminals, whereas the others non-terminals each consist of multiple options.

Rules may be duplicated for the same non-terminal to make a particular expansion more likely than others. For example, suppose the above grammar were modified as follows:

```
sentence ::= article object verb
article ::= the | a
object ::= cat | cat | dog
verb ::= runs | walks
```

This grammar would produce the same sentences as the original grammar, but sentences containing “cat” would be twice as likely to occur as sentences containing “dog.”

In addition, for this assessment, you may assume the following about all BNF rules:

- Each line will contain *exactly one occurrence* of `::=` which will be the separator between the name of a non-terminal and its options.
- A pipe (|) will separate each option for a non-terminal. If there is only one option for a particular non-terminal (like with `sentence` above), there will be no pipe on that line.
- Whitespace separates tokens but doesn’t have any special meaning. There will be at least one whitespace character between each part of a single rule. Extra whitespace should be ignored.
- Symbols are case-sensitive. (For example, `<S>` would not be considered the same symbol as `<s>`.)
- *A terminal* is any symbol that does not appear on the left-hand side of a rule.
- The text before the “`:=`” is not empty, does not contain a pipe (|) character, and does not contain any whitespace.
- The text after the “`:=`” will be nonempty.

**Program Behavior**

In this assessment you will write a class that accepts a list of rules for a grammar in Backus-Naur Form and allows the client to randomly generate elements of the grammar. You will use recursion to implement the core of your algorithm.
We have provided you with a client program, GrammarMain.java, that handles the file processing and user interaction. This program reads a BNF grammar input text file and passes its entire contents to you as a List of Strings. You will write a class GrammarSolver that generates random results based on the rules provided.

**GrammarSolver**

Your GrammarSolver class should have the following constructor:

```java
public GrammarSolver(List<String> rules)
```

This constructor should initialize a new grammar over the given BNF grammar rules where each rule corresponds to one line of text. You should use regular expressions (see below) to break apart the rules and store them into a Map so that you can look up parts of the grammar efficiently later.

You should not modify the list passed in. You should throw an IllegalArgumentException if the list is empty or if there are two or more entries in the grammar for the same non-terminal.

Your GrammarSolver should also implement the following public methods:

```java
public boolean grammarContains(String symbol)
```

This method should return true if the given symbol is a non-terminal in the grammar and false otherwise.

For example, for the grammar above, grammarContains("sentence") would return true and grammarContains("foo") or grammarContains("boy") ("boy" is a terminal in the language) would return false.

```java
public String getSymbols()
```

This method should return a string representation of the various nonterminal symbols from the grammar as a sorted, comma-separated list enclosed in square brackets.

For example, calling getSymbols() for the previous grammar would give: 

```
[article, object, sentence, verb]
```

```java
public String[] generate(String symbol, int times)
```

This method should generate times random occurrences of the given symbol and return them as a String[]. Each string generated should be compact in the sense that there should be exactly one space between each terminal and there should be no leading or trailing spaces.

If times is negative, you should throw an IllegalArgumentException. If the String argument passed is not a non-terminal in your grammar you should throw an IllegalArgumentException.

When generating a non-terminal symbol in your grammar, each of the rules on the right-hand side of the grammar should be applied with equal probability.
Sample Grammar and Executions

Complex BNF (sentence.txt)

<sentence>::=<nounp> <verbp>
<nounp>::=<det> <adjs> <noun>|<propnoun>
<propnoun>::=Hadi|Jazmin|Ali|Spot|Fred|Elmo
<adjs>::=<adj>|<adj> <adjs>
<adj>::=big|green|wonderful|faulty|subliminal|pretentious
<det>::=the|a
<noun>::=dog|cat|man|university|father|mother|child|television
<verbp>::=<transverb> <nounp>|<intransverb>
<transverb>::=taught|honored|waved to|helped
<intransverb>::=died|collapsed|laughed|wept

Example Random Sentence Diagram

Partial Example Execution (user input underlined)
Welcome to the cse143 random sentence generator.

What is the name of the grammar file? sentence.txt

Available symbols are:
[<adj>, <adjs>, <det>, <intransverb>, <noun>, <nounp>, <propnoun>, <sentence>, <transverb>, <verbp>]

What do you want generated (return to quit)? <sentence>
How many do you want me to generate? 5
a pretentious subliminal subliminal green dog collapsed
the big cat waved to a big subliminal big child
da wonderful child collapsed
the pretentious dog waved to a green faulty dog
Ali waved to Fred

Available symbols are:
[<adj>, <adjs>, <det>, <intransverb>, <noun>, <nounp>, <propnoun>, <sentence>, <transverb>, <verbp>]

What do you want generated (return to quit)?

More example program executions are found at the end of the spec.
Implementation Guidelines

GrammarSolver Constructor

For this assessment, you MUST represent your grammar using a Map, where the keys of the map are the non-terminals of the grammar, and the values are the options for expansion the corresponding non-terminal. You should choose an appropriate data structure for the values in your Map to effectively represent the grammar rules and make the operations required by the class convenient and efficient.

generate Algorithm

The generate method will generate a random occurrence of a given non-terminal $NT$. You MUST use the following recursive algorithm in your implementation of this method:

Choose a random expansion rule $R$ for the non-terminal $NT$. For each of the symbols in the rule $R$, generate a random occurrence of that symbol. If the symbol is a terminal, the expansion is simply the symbol itself. If the symbol is a non-terminal, you should generate an expansion using a recursive call.

Remember that it is acceptable to have a loop inside your recursion. (In fact, you will likely want one as part of this algorithm!) The directory crawler program from class will serve as a good guide for how to write this program. In that example, we iterated over the different files in a directory and used recursion to list the files in each subdirectory. For your GrammarSolver, you will iterate over the different symbols in the chosen rule and use recursion to generate an expansion for each symbol. You may also find that you will want to use a public/private pair for this recursive task.

Testing Your Solution

We are providing another tool that is linked on the section for this assignment to check the output of your generate method to make sure it is producing valid output. You can test that the correct whitespace is produced from generate by using some non-whitespace character (e.g. ~) instead of spaces and inspecting the output visually.

Splitting Strings

In this assignment, it will be useful to know how to split strings apart in Java. In particular, you will need to split the various options for rules on the | character, and then, you will need to split the pieces of a rule apart by spaces.

To do this, you should use the split method of the String class, which takes a String delimiter (e.g. “what to split by”) as a parameter and returns your original large String as an array of smaller Strings.

The delimiter String passed to split is called a regular expression, which are strings that use a particular syntax to indicate patterns of text. A regular expression is a String that “matches” certain sequences. For instance, “abc” is a regular expression that matches “a followed by b followed by c”.

You do not need to have a deep understanding of regular expressions to complete this assessment. Here are some specific regular expressions that will help you with particular splitting steps for your class:

- Splitting Non-Terminals from Rules. Given a String, line, to split line based on where ::= occurs, you could use the regular expression “::=” (since you are looking for these literal characters). For example:

```java
String line = "example ::=foo bar |baz";
String[] pieces = line.split("::="); // ["example", "foo bar |baz"]
```
- **Splitting Different Rules.** Given a String, rules, to split rules based on where the | character is, it looks similar to the above, except, in regular expressions, | is a special character. So, we must escape it (just like \n or \t). So, the regular expression is "\|". (Note that we need two slashes because slashes themselves must be escaped in Strings.) For example:

```java
String rules = "foo bar|baz |quux mumble";
String[] pieces = rules.split("\|" ); // ["foo bar", "baz ", "quux mumble"]
```

- **Splitting Apart a Single Rule.** Given a String, rule, to split rule based on whitespace, we must look for “at least one whitespace”. We can use \s to indicate “a single whitespace of any kind: \t, space, etc. And by adding + afterwards, the regular expression is interpreted as “one or more of whitespace”. For example:

```java
String rule = "the quick brown fox";
String[] pieces = rule.split("\s+" ); // ["the", "quick", "brown", "fox"]
```

### Removing Whitespace from the Beginning and the End of a String

One minor issue that comes up with splitting on whitespace as above is that if the String you are splitting begins with a whitespace character, you will get an empty String at the front of the resulting array. Given a String, str, we can create a new String that omits all leading and trailing whitespace removed:

```java
String str = " lots of spaces 	";
String trimmedString = str.trim(); // "lots of spaces"
```

### Development Strategy and Hints

The generate method is the most difficult, so we strongly suggest you write it last. Remember that it is helpful to tackle difficult methods using “iterative development” where you solve simple versions of the problem first.

Random programs can be difficult to validate correctness, and the generate method you will implement uses randomness to decide which rule for a given non-terminal to use. To help you debug and validate your output, we have provided a grammar verifier tool on the course website that verifies your output follows the grammar rules (but ignores whitespace).

If your recursive method has a bug, try putting a `debug println` that prints your parameter values to see the calls being made.

### Code Quality Guidelines

In addition to producing the behavior described above, your code should be well-written and meet all expectations described in the grading guidelines, Code Quality Guide, and Commenting Guide. For this assessment, pay particular attention to the following elements:

**SortedMap**

Because we want you to guarantee the keys of your map are sorted, we will ask you to use the `SortedMap<K, V>` interface for this assignment instead of the `Map<K, V>` interface. The `SortedMap` interface is essentially the same as the `Map` interface, except it requires the keys be sorted. This means `TreeMap` is a valid `SortedMap` implementation, but `HashMap` is not. You can use all the same methods on a `SortedMap` as you could on a `Map`.

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**Generic Structures**

You should always use generic structures. If you make a mistake in specifying type parameters, the Java compiler may warn you that you have “unchecked or unsafe operations” in your program. If you use jGRASP, you may want to change your settings to see which line the warning refers to. Go to Settings/Compiler Settings/Workspace/Flags/Args and then uncheck the box next to “Compile” and type in: -Xlint:unchecked

**Data Fields**

Properly encapsulate your objects by making data your fields private. Avoid unnecessary fields; use fields to store important data of your objects but not to store temporary values only used in one place. Fields should always be initialized inside a constructor or method, never at declaration.

**Exceptions**

The specified exceptions must be thrown correctly in the specified cases. Exceptions should be thrown as soon as possible, and no unnecessary work should be done when an exception is thrown. Exceptions should be documented in comments, including the type of exception thrown and under what conditions.

**Commenting**

Each method should have a header comment including all necessary information as described in the Commenting Guide. Comments should be written in your own words (i.e. not copied and pasted from this spec) and should not include implementation details.

**Running and Submitting**

If you believe your behavior is correct, you can submit your work by clicking the "Mark" button in the Ed assessment. You will see the results of some automated tests along with tentative grades. **These grades are not final until you have received feedback from your TA.**

You may submit your work as often as you like until the deadline; we will always grade your most recent submission. Note the due date and time carefully—**work submitted after the due time will not be accepted**.

**Getting Help**

If you find you are struggling with this assessment, make use of all the course resources that are available to you, such as:

- Reviewing relevant examples from class
- Reading the textbook
- Visiting support hours
- Posting a question on the message board

**Collaboration Policy**

Remember that, while you are encouraged to use all resources at your disposal, including your classmates, **all work you submit must be entirely your own**. In particular, you should NEVER look at a solution to this assessment from another source (a classmate, a former student, an online repository, etc.). Please review the full policy in the syllabus for more details and ask the course staff if you are unclear on whether or not a resource is OK to use.
Reflection
In addition to your code, you must submit answers to short reflection questions. These questions will help you think about what you learned, what you struggled with, and how you can improve next time. The questions are given in the file GrammarSolverReflection.txt in the Ed assessment; type your responses directly into that file.

Sample Execution #1 (user input underlined)
Welcome to the cse143 random sentence generator.

What is the name of the grammar file? sentence.txt

Available symbols to generate are:
[<adj>, <adjs>, <det>, <intransverb>, <noun>, <nounp>, <proppn>, <sentence>, <transverb>, <verbp>]
What do you want generated (return to quit)? <det>
How many do you want me to generate? 5
a
the
a
the

Available symbols to generate are:
[<adj>, <adjs>, <det>, <intransverb>, <noun>, <nounp>, <proppn>, <sentence>, <transverb>, <verbp>]
What do you want generated (return to quit)? <nounp>
How many do you want me to generate? 5
Elmo
a green big pretentious green pretentious subliminal university
the pretentious cat
Jazmin
the pretentious subliminal mother

Available symbols to generate are:
[<adj>, <adjs>, <det>, <intransverb>, <noun>, <nounp>, <proppn>, <sentence>, <transverb>, <verbp>]
What do you want generated (return to quit)? <sentence>
How many do you want me to generate? 15
Spot laughed
the green cat waved to a subliminal university
Fred waved to Fred
the pretentious subliminal green wonderful university wept
a faulty big wonderful child collapsed
a wonderful wonderful television wept
a pretentious subliminal mother taught Hadi
Ali honored the subliminal faulty father
a big wonderful father honored Spot
the subliminal green wonderful university waved to a big wonderful father
Elmo taught Hadi
a big man wept
the subliminal green subliminal faulty big cat died
Spot collapsed
a green green cat honored a green university

Available symbols to generate are:
[<adj>, <adjs>, <det>, <intransverb>, <noun>, <nounp>, <proppn>, <sentence>, <transverb>, <verbp>]
What do you want generated (return to quit)?
Welcome to the cse143 random sentence generator.

What is the name of the grammar file? sentence2.txt

Available symbols to generate are: [E, F1, F2, OP, T]
What do you want generated (return to quit)? T
How many do you want me to generate? 5
42 - y
x
x
(( 1 ))

Available symbols to generate are: [E, F1, F2, OP, T]
What do you want generated (return to quit)? E
How many do you want me to generate? 10
x - 1
0
sin ( 1 + 92 + - 1 / 42 )
max ( y , 92 )
42 % 1
- 42
92
1
92
42 - sin ( 1 )

Available symbols to generate are: [E, F1, F2, OP, T]
What do you want generated (return to quit)?